RESEARCH MEMORANDUM

FREE-SPINNING TUNNEL INVESTIGATION OF A $\frac{1}{20}$-SCALE

MODEL OF THE DOUGLAS X-3 AIRPLANE

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

An investigation of the spin and spin-recovery characteristics of a $\frac{1}{20}$-scale model of the Douglas X-3 airplane was conducted in the Langley 20-foot free-spinning tunnel. It was found that, at the Reynolds number of the present tests, the pitching-moment characteristics of a scale model were not typical of larger scale results. The spinning characteristics of a model with moment characteristics representative of larger scale were obtained by the adoption of a modified fuselage nose contour.

The results of the tests indicated that, at altitudes near 15,000 feet and probably up to about 30,000 feet, the X-3 airplane will not exhibit any unusual trim tendencies and it will be difficult to obtain erect spins in the airplane unless the ailerons are full with the spin. Recoveries from spins obtained will be satisfactory if all controls are neutralized. Inverted spins obtained will be satisfactorily terminated by rudder reversal. Analysis indicates that, for high subsonic Mach numbers such as may be obtained at very high altitudes, the airplane may trim at a flat stalled attitude and it may be necessary for the airplane to descend to a lower altitude before normal flight attitude can be regained.

INTRODUCTION

Results of previous dynamic tests of a model of the X-3 airplane conducted in the 20-foot free-spinning tunnel (reference 1) indicated a tendency for the model to trim at very high angles of attack (70° to 80°). Results of static force tests, also presented in reference 1, indicated that the unusual trim conditions were associated with the high cross-flow drag on the fuselage, drag due to the component of air flow perpendicular to the fuselage, at the subcritical Reynolds number at which the dynamic tests were conducted. Static tests at higher Reynolds numbers indicated that the corresponding airplane would not exhibit flat trimming tendencies at low subsonic Mach numbers. The present investigation was undertaken to determine the probable spin and spin-recovery characteristics of the X-3 airplane by tests of a $\frac{1}{20}$-scale model, the nose of which could readily be replaced by a sting to approximate the larger Reynolds number pitching moments, inasmuch as the size of model required to attain the desired Reynolds number could not be accommodated in the spin tunnel. The present investigation included force tests and erect-spin tests of the model both in its original and modified configurations, and inverted spin tests of the model in its modified configuration.

SYMBOLS

b	wing span, feet
S	wing area, square feet
$\bar{c}$	mean aerodynamic chord, feet
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
$z/\bar{c}$	ratio of perpendicular distance between center of gravity and wing-center line to mean aerodynamic chord (positive when center of gravity is below line)
m	mass of airplane, slugs
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-feet^2
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter
$\frac{I_Z - I_X}{mb^2}$	inertia pitching-moment parameter

α	angle of attack, degrees (for the spin data presented on the charts, α is the angle between the fuselage reference line and vertical and is approximately equal to the absolute value of the angle of attack at plane of symmetry)
ψ	angle of yaw, degrees
ϕ	angle between wing-span axis and horizontal, degrees
Ω	full-scale angular velocity about spin axis, revolutions per second
V	velocity of air stream or full-scale true rate of descent, feet per second
ρ	air density, slugs per cubic foot
μ	relative density of airplane $(m/\rho Sb)$
ν	kinematic viscosity, square feet per second
δ_e	deflection of horizontal tail, degrees
R	Reynolds number, $V\bar{c}/\nu$
M	pitching moment, foot-pounds
L	lift, pounds
D	drag, pounds
C_m	pitching moment coefficient (about the center of gravity) $\left(\frac{M}{\frac{1}{2}\rho SV^2\bar{c}}\right)$
C_L	lift coefficient $\left(\frac{L}{\frac{1}{2}\rho V^2 S}\right)$
C_D	drag coefficient $\left(\frac{D}{\frac{1}{2}\rho V^2 S}\right)$

APPARATUS AND METHODS

Model

The investigation was conducted on a $\frac{1}{20}$-scale model, built at the Langley Laboratory, of the X-3 airplane shown in figure 1. Provision was made for modifying the model to compensate for scale effect on the fuselage by replacing the normal nose with a sting having approximately one-fourth the projected area of the normal nose section (the sting nose being 11.5 inches long and tapering from $\frac{1}{8}$-inch diameter at the tip to $\frac{5}{8}$-inch diameter at the base). Figures 2 and 3 are photographs of the model in its original and modified configurations, respectively. A comparison of the horizontal tail used in the investigation of reference 1 and the larger horizontal tail currently planned for the airplane and used for the spin tests of the present investigation is shown in figure 4. The dimensional characteristics of the airplane represented by the model are given in table I and the mass characteristics on table II.

The model was ballasted to obtain dynamic similarity to the airplane at 15,000 feet (ρ = 0.001496 slugs/cu ft). A remote-control mechanism was installed in the model to actuate the controls for the recovery attempts with moments exerted on the controls during the recovery attempts being sufficient to move them rapidly to the desired position.

Wind Tunnel and Testing Technique

Spin tests.- The spin tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is generally similar to that described in reference 2 for the Langley 15-foot free-spinning tunnel except that the model-launching technique has been changed. With the controls set in the desired position, the model is launched by hand with rotation into the vertically rising air stream. After a number of turns in the established spin, a recovery attempt is made by moving one or more controls by means of the remote-control mechanism. After recovery, the model dives into a safety net. The spin data obtained from these tests are then converted to corresponding full-scale values by methods also described in reference 2.

In accordance with standard spin-tunnel procedure, tests were performed to determine the spin and recovery characteristics of the model for the normal spinning control configuration (elevator full up, ailerons neutral, and rudder full with the spin) and for various other aileron-elevator combinations including neutral and maximum settings of the surfaces. Recovery was generally attempted by rapid reversal of the rudder from full with to full against the spin. Recovery attempts were also made by movement of the ailerons alone or in combination with rudder movement.

For normal spins, turns for recovery are measured from the time the controls are moved to the time the rotation ceases. A satisfactory recovery from a spin for the model is considered to be two turns or less. For the spins which had a rate of descent in excess of that which can be attained in the tunnel, the rate of descent was recorded as greater than the velocity at the time the model hit the safety net, that is, >300 feet per second full scale. Recovery results obtained from these spins are considered conservative; that is, the recoveries are somewhat slower than those that would have been obtained had the model been in its final steeper spin attitude. For cases where the model recovered without control movement when launched in a spinning attitude with the controls set for the spin, the condition was recorded as "no spin."

Balance tests.- The balance tests were made by mounting the model on the spin tunnel strain-gage balance described in reference 3. These tests were made primarily to evaluate pitching-moment characteristics of the unmodified and modified (sting nose) versions of the model.

TEST CONDITIONS

The spin tests were performed with the unmodified and modified (sting nose) model in the clean condition for the original design gross weight, tabulated as loading number 1 in table II. All dynamic tests were made with the larger revised horizontal tail surfaces, as previously indicated. Although the design gross-weight loading of the airplane was revised during the course of the model tests (table II), the model loading was not altered to conform to this revised loading because it was felt that the results would be essentially the same for either the original or revised design gross-weight conditions. The mass characteristics of the model at the beginning and at the end of the investigation are tabulated in table II. The mass characteristics and inertia parameters for the various loading conditions listed in table II are plotted in figure 5. The maximum control deflections used in the tests were:

Rudder, degrees	20 right, 20 left
All-movable horizontal tail, degrees	23 up, 9 down
Ailerons, degrees	12 up, 12 down

The balance tests were conducted at a Reynolds number of 150,000 (based on $\bar{c}$), which corresponded to the approximate Reynolds number at which the spin tests were performed. The Mach number of the tests was approximately 0.06. For comparative purposes, the small horizontal tail used for the investigation of reference 1, having deflections of 25° up, neutral, and 10° down, was installed on the model for most of the balance tests of the present investigation.

RESULTS AND DISCUSSION

The pitching-moment characteristics of the unmodified model are shown in figure 6 and are compared with data at the larger Reynolds number obtained in reference 1. As previously indicated, the small horizontal tail was used on the $\frac{1}{20}$-scale spin model for these tests to afford a direct comparison with the larger-scale data. The low Reynolds number results show high angle-of-attack trim conditions for all horizontal tail settings. On the other hand, the pitching-moment curves obtained at higher Reynolds number (from reference 1) are indicated to be stable over most of the angle-of-attack range and indicate no unusual trim conditions (also shown on fig. 6). These differences in pitching-moment characteristics are explained in reference 1 as being attributable to the change in cross-flow drag coefficient on the fuselage with change in Reynolds number. Because it was believed that the high angle-of-attack trim conditions exhibited by the $\frac{1}{20}$-scale spin model were due primarily to the large drag on the nose at low Reynolds number, the fuselage nose was replaced by a sting having approximately one-fourth the projected area of the normal nose in an attempt to simulate larger Reynolds number pitching-moment data. The results of these tests, presented in figure 7, show good qualitative agreement between the pitching-moment data of the modified $\frac{1}{20}$-scale spin model and the larger-scale pitching-moment data obtained from reference 1. As has been stated previously, the small horizontal tail was on the model for these tests; however, it is believed that, for low subsonic Mach numbers, the spin model with the sting nose and large horizontal tail installed should simulate closely the pitching-moment characteristics of the full-scale airplane with the large tail installed. The pitching-moment characteristics of the model modified by the sting-nose installation are considered to be similar to those that the full-scale airplane might experience at spinning attitudes at 15,000 feet. Brief computations made using low-speed aerodynamic data indicated that similar pitching-moment characteristics might be expected in spins or stalled glides up to approximately 30,000 feet beyond which Mach effects may be encountered.

As pointed out in reference 1, the pitching-moment characteristics of the unmodified spin model should be somewhat similar to full-scale pitching moments at high subsonic speeds. As is explained in reference 1, this result is due to the similarity of the cross-flow drag coefficient over bodies of revolution at cross-flow Mach numbers exceeding approximately 0.5 and the cross-flow drag coefficients obtained at the low Reynolds number and low Mach number at which the spin tests were conducted. Thus, the results of the investigation presented herein for the unmodified model are expected to be applicable to the airplane for very high test altitudes, (which may be as low as 30,000 feet) where high speeds would be expected even at spinning or stalled glide attitudes.

Spin Tests of Modified (Sting Nose) Model

Erect spins.- The results of the erect spin tests of the model with large horizontal tail and modified (sting) nose installed for the original design gross weight loading (loading 1 in table II and fig. 5) are presented on chart 1.

As is shown on chart 1, erect spins were obtained for only two control settings, ailerons full with the spin with the horizontal tail set full up or full down. For all other control configurations, the initial rotation imparted on launching damped out rapidly and the model either dived when ailerons were neutral or with the spin (stick right in a right spin) or sometimes went into a steep aileron roll in the direction of the aileron setting when the ailerons were against the spin. In no instance did the model exhibit any flat-trimming tendencies. When ailerons were full with the spin and the horizontal tail was full down, an extremely unusual motion occurred, the model rolling rapidly about its longitudinal body axis while rotating about a vertical axis as in a normal spin. Although this motion could not be stopped by reversal of the rudder, simultaneous neutralization of rudder and ailerons terminated the motion rapidly. The spin obtained with horizontal tail full up was very steep and could also be terminated satisfactorily by simultaneous neutralization of rudder and ailerons. Accordingly, it appears that neutralization of all controls should terminate any turning motion above the stall obtained on the airplane.

No tests were conducted for any of the other loading conditions possible on the airplane, table II, inasmuch as it was believed that the results for the other possible airplane loadings would be similar to those obtained for the condition tested.

Inverted spins.- The results of the inverted-spin tests of the modified model with the large horizontal tail installed are presented in chart 2. It should be noted that the order used for presenting the data for inverted spins is different from that used for erect spins. For inverted spins, controls crossed for the established spin (right rudder pedal forward and stick to pilot's left for a spin to the pilot's right) is presented to the right of the chart and stick back is presented at the bottom. When the controls are crossed in the established spin, the ailerons aid the rolling motion; when the controls are together, the ailerons oppose the rolling motion.

The inverted spins obtained were very steep and recoveries by rudder reversal alone were generally satisfactory. The model indicated no flat trimming tendencies. The results indicate that rudder reversal will insure satisfactory recoveries from any inverted spins obtained on the airplane.

Spin Tests of Unmodified Model

The results of the erect spin tests of the unmodified model (normal nose) with the large horizontal tail installed are presented in chart 3. As has been stated previously and as had been indicated in reference 1, it is believed that the pitching-moment characteristics for this model configuration at the low Reynolds number at which the spin-tunnel tests were made should be somewhat similar to the pitching-moment characteristics of the full-scale airplane at high subsonic Mach numbers. It is expected, as previously indicated, that the results of these model tests should apply to the airplane at very high altitudes in stalled or spinning attitudes.

Results of the model spin tests, chart 3, showed that after the launching rotation was expended, the model tended to remain at a high angle of attack, approximately 70°, for the neutral and up settings of the horizontal tail. For these horizontal tail settings, the model generally rotated slowly in the tunnel while oscillating approximately $\pm 20^{\circ}$ in roll; the radius of the model path increased as the motion progressed and in some instances the rotation was observed to stop and the model entered a flat stalled glide. When the ailerons were against the spin for the neutral and up settings of the horizontal tail, the model sometimes rolled rapidly in the direction of the aileron setting, the fuselage remaining at a flat stalled attitude. Although not specifically tested, neutralization of the ailerons should terminate any such motion obtained on the airplane; however, the airplane should trim flat for these elevator settings. When the horizontal tail was down, motions similar to those obtained with the horizontal tail neutral or up were encountered except that when the ailerons were neutral or with the spin the model dived out after the turning motion was terminated, indicating that placing the horizontal tail down was effective in restoring the model to normal flight attitudes for settings of the ailerons neutral and with the spin.

No balance tests were conducted with the horizontal tail down for this configuration of the model, but tests were conducted with the horizontal tail at neutral and the results of these tests are presented in figure 8. These test results are consistent with the results of the dynamic tests and indicate a trim condition at approximately 70° angle of attack with the horizontal tail at neutral. On the basis of the force and spin tests, the longitudinal trim characteristics of the unmodified model are considered marginal inasmuch as it was indicated that the horizontal tail must be moved down well beyond neutral to pitch the model out of a stalled attitude. Because of possible differences in pitching-moment characteristics between model and airplane, however, it is possible that even full down movement of the horizontal tail may not be effective in pitching the airplane out of any high stalled attitudes obtained, and it may be necessary for the airplane to descend to lower altitudes and corresponding lower Mach numbers to regain normal flight.

It should be noted that the results of these tests are similar to results of the dynamic tests reported in reference 1 except that, when deflected full down, the small horizontal tail installed on the model for the tests reported in reference 1 was not effective in terminating the flat trimmed attitudes obtained.

No inverted spin tests were conducted for this configuration of the model because it was believed that the results of inverted spin tests would be generally similar to the results obtained for erect spins and any flat trim condition obtained could be effectively terminated by setting the horizontal tail down (relative to ground) and stick laterally neutral.

CONCLUSIONS

Based on results of tests of a $\frac{1}{20}$-scale model of the Douglas X-3 airplane, the following conclusions regarding the spin and recovery characteristics of the airplane are made:

1. At test altitudes up to approximately 30,000 feet, the airplane will probably not spin erect unless the ailerons are full with the spin (stick right in a right spin). Any spinning motion obtained should be terminated satisfactorily by neutralization of all controls. No unusual trim conditions should be obtained.

2. Any inverted spins entered in the vicinity of 15,000 to 30,000 feet altitude will be satisfactorily terminated by rudder reversal.

3. At very high altitudes and associated high subsonic Mach numbers, the airplane may be capable of trimming at high angles of attack and it may be necessary for the airplane to descend to lower altitudes to recover from any flat stalled attitude obtained.

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REFERENCES

1. Burk, Sanger M., Jr., and Hultz, Burton E.: Static Longitudinal Stability and Dynamic Characteristics at High Angles of Attack at Low Reynolds Number of a Model of the X-3 Supersonic Research Airplane. NACA RM L50L19, 1951.

2. Zimmerman, C. H.: Preliminary Tests in the N.A.C.A. Free-Spinning Wind Tunnel. NACA Rep. 557, 1936.

3. Stone, Ralph W., Jr., Burk, Sanger M., Jr., and Bihrle, William, Jr.: The Aerodynamic Forces and Moments on a $\frac{1}{10}$-Scale Model of a Fighter Airplane in Spinning Attitudes as Measured on a Rotary Balance in the Langley 20-Foot Free-Spinning Tunnel. NACA TN 2181, 1950.

TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE X-3 AIRPLANE

AS SIMULATED FOR THE MODEL TESTS

Over-all length, ft	62.7
Wing:	
Span, ft	22.7
Area, sq ft	166.5
Airfoil section	Modified hexagon
Aspect ratio	3.1
Taper ratio	0.388
Thickness ratio, percent chord	4.5
Incidence	0
Dihedral	0
Sweepback (50 percent chord), deg	8
Mean aerodynamic chord, ft	7.84
Leading edge of $\bar{c}$ rearward of leading edge of root chord, ft	2.06
Ailerons:	
Area (rearward of hinge line), sq ft	8.5
Span, percent wing span	29.8
Flaps:	
Leading-edge	
Area (forward of hinge line), sq ft	17.3
Span, percent wing span	73.2
Trailing-edge	
Area (rearward of hinge line), sq ft	18.5
Span, percent wing span	44.6
Horizontal tail surfaces:	
Total area, sq ft	43.42
Span, ft	13.77
Aspect ratio	4.37
Taper ratio	0.410
Dihedral	0
Sweepback, at 50 percent chord	10.57
Distance from center of gravity to hinge line, ft	22.40
Vertical tail surfaces:	
Total area, sq ft	23.7
Rudder area (rearward of hinge line), sq ft	6.1
Aspect ratio	1.3
Taper ratio	0.298
Sweepback at 50 percent chord, deg	30

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TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR THE LOADING CONDITIONS POSSIBLE ON THE AIRPLANE AND FOR THE LOADINGS TESTED ON THE MODEL

[Model values converted to corresponding full-scale values; moments of inertia are given about center of gravity]

Number	Loading	Weight (lb)	Center-of-gravity location		Airplane relative density, μ		Moments of inertia (slug-ft^2)			Mass parameters		
			$x/\bar{c}$	$z/\bar{c}$	Sea level	15,000 feet	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
Airplane values												
1	Original design gross weight	20,800	0	-12.6	71.86	114.34	6,686	71,170	74,405	-1937×10^{-4}	-97×10^{-4}	2034×10^{-4}
2	Revised design gross weight	20,800	0	——	71.86	114.34	4,098	77,855	81,090	-2216	-97	2313
3	Take off gross weight	23,700	0	——	81.86	130.27	4,745	87,992	91,011	-2195	-80	2275
4	Alternate design gross weight	25,200	0	——	86.98	138.41	5,392	88,423	91,442	-2060	-75	2135
5	Weight less fuel	16,800	0	——	58.06	92.39	3,558	64,670	67,503	-2272	-105	2377
Model values												
1a	Modified model at start tests	21,086	0.6	-9.7	72.86	115.81	7,000	72,771	74,899	-1949	-63	2012
1b	Modified model at end tests	21,297	2.7	-10.1	73.59	116.97	6,226	71,088	74,435	-1903	-98	2001
1c	Unmodified model at start tests	20,248	0.2	-7.1	69.96	111.21	7,022	73,438	76,147	-2050	-84	2134
1d	Unmodified model at end tests	21,347	1.1	-7.5	73.76	117.25	7,162	75,787	78,792	-2009	-88	2097

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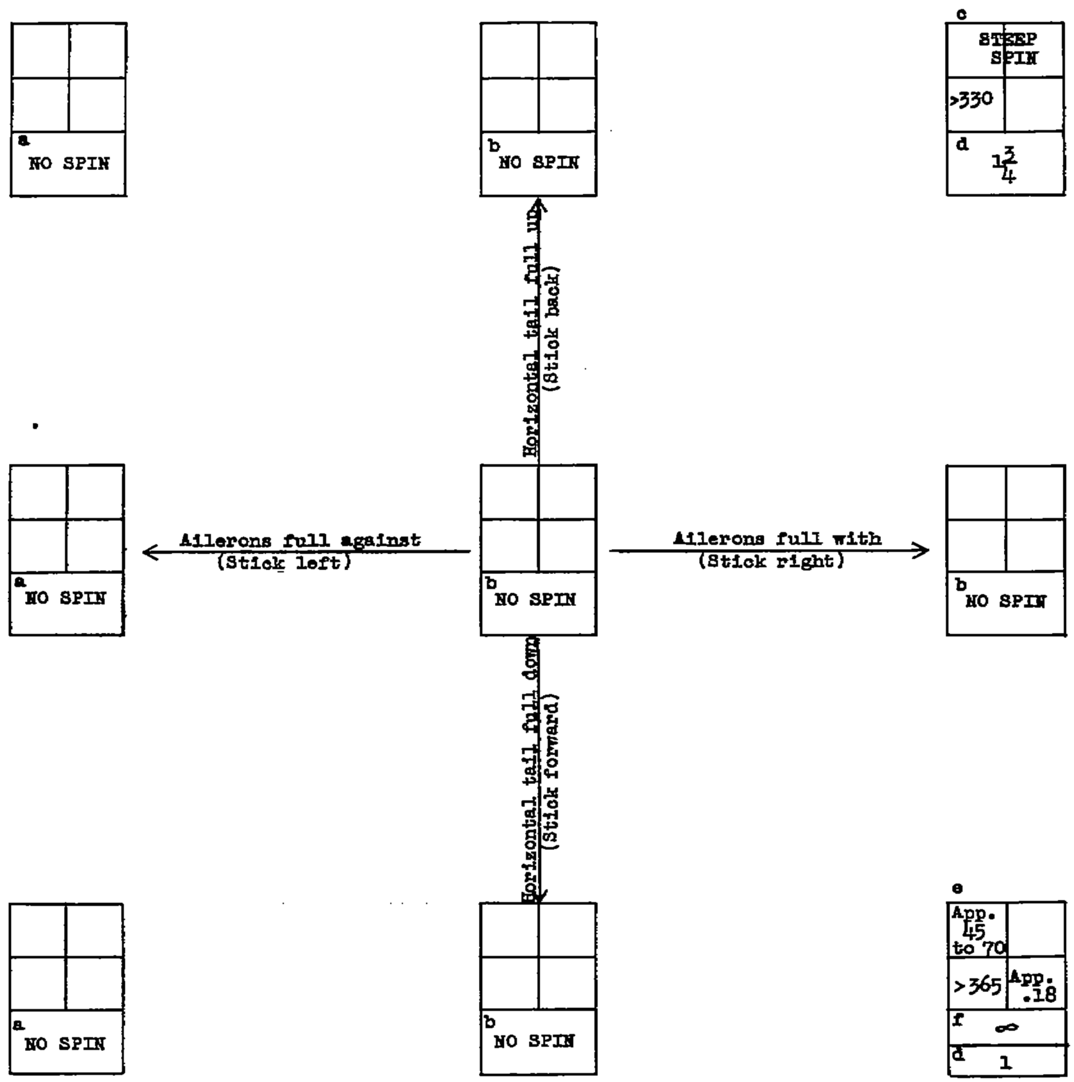
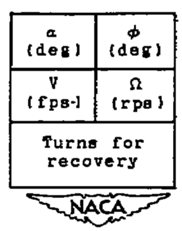
CHART 1.- ERECT SPIN AND RECOVERY CHARACTERISTICS OF MODIFIED MODEL (STING NOSE INSTALLED)

[Loadings 1a and 1b on Table II; rudder initially set full with the spin; control movement for recovery as indicated; spins to pilot's right]





Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

[a]After launching rotation was expended, model usually went into a steep rapid left roll.

[b]After launching rotation expended, model dives.

[c]A "no spin" condition also obtained.

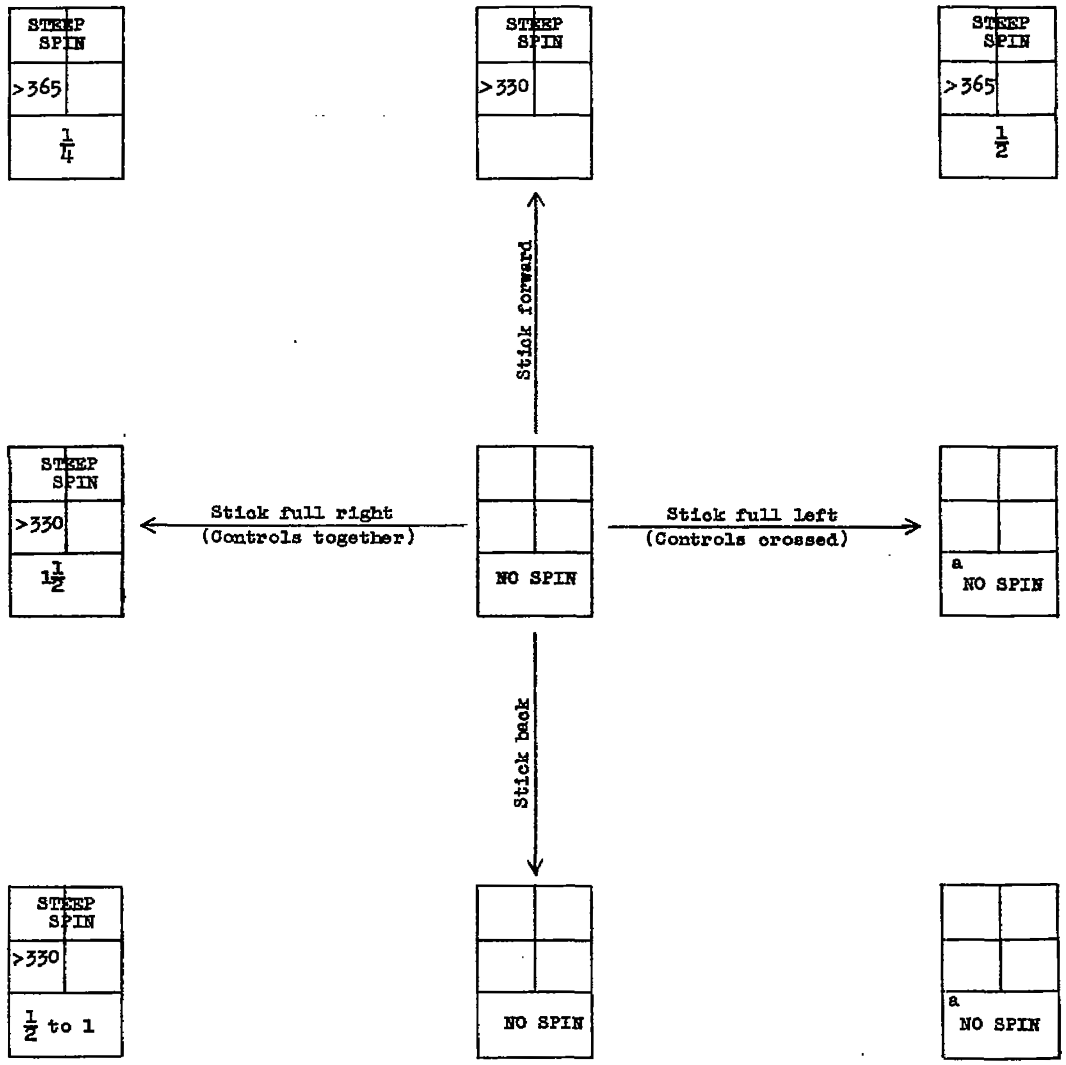
[d]Recovery attempted by simultaneous neutralization of rudder and ailerons.

[e]Model rotates about a vertical axis and at the same time rolls to right.

[f]Recovery attempted by rudder reversal.

CHART 2.- INVERTED SPIN AND RECOVERY CHARACTERISTICS OF MODIFIED MODEL (STING NOSE INSTALLED)

[Loadings 1a and 1b on Table II; rudder initially set full with the spin; recovery attempted by full rapid reversal; spins to pilot's right]



[a]Model goes into an aileron roll after launching rotation expended.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

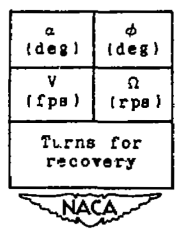
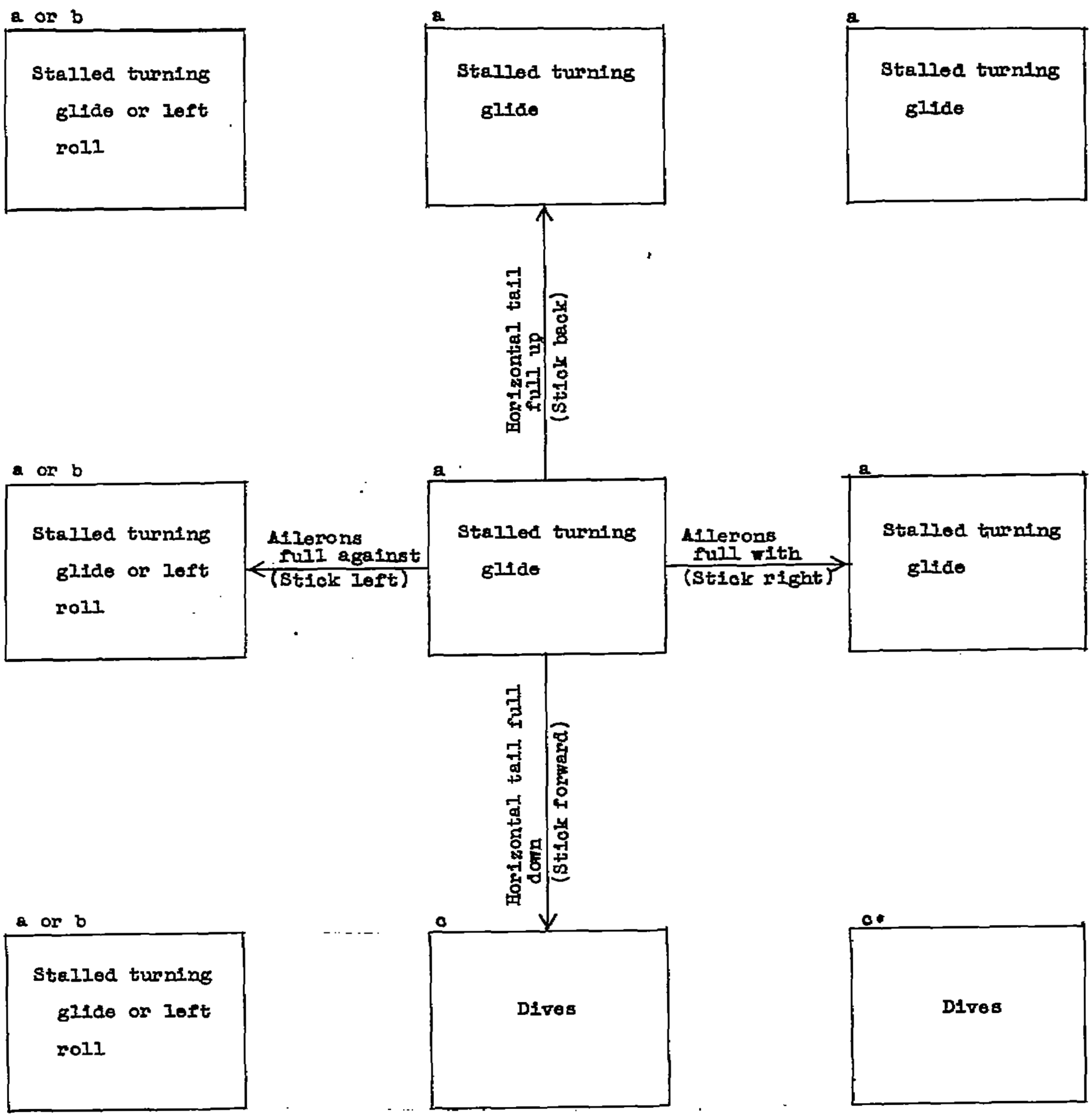


CHART 3.- ERECT SPIN CHARACTERISTICS OF UNMODIFIED MODEL

[Loadings 1c and 1d on Table II; rudder set full with the spin; spins to pilot's right]



[a]Model rotates slowly in tunnel while oscillating approximately ±20° in roll. Angle of attack of model approximately 70°. Radius of turn increases as motion progresses and model sometimes goes into a flat stalled glide.

[b]After launching rotation expended model goes into a rapid, left roll, the attitude of the fuselage being very flat.

[c]After turning rotation ceases model goes into a dive.

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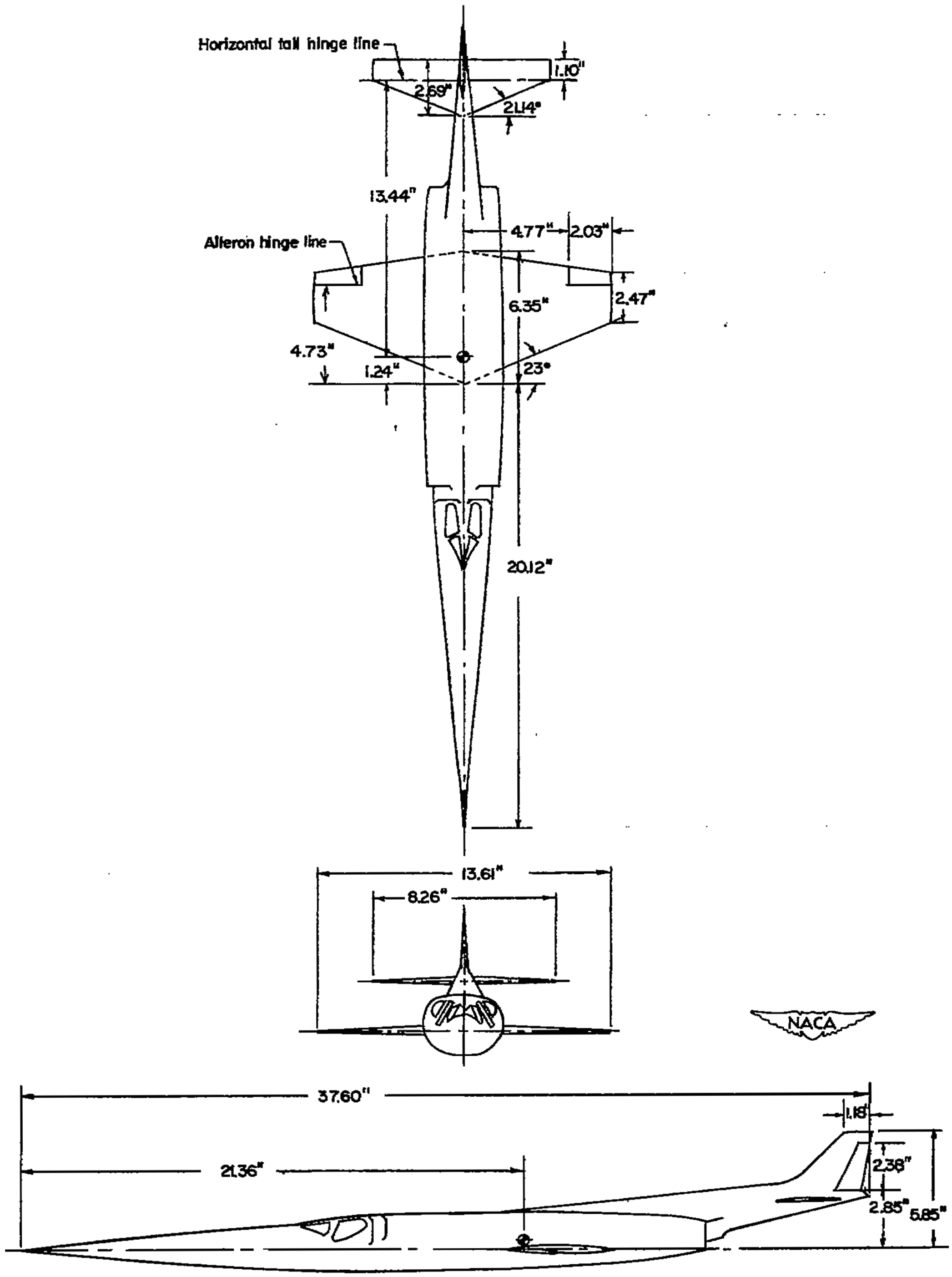

Figure 1.- Three-view drawing of the unmodified $\frac{1}{20}$-scale model investigated. (Large horizontal tail installed.)

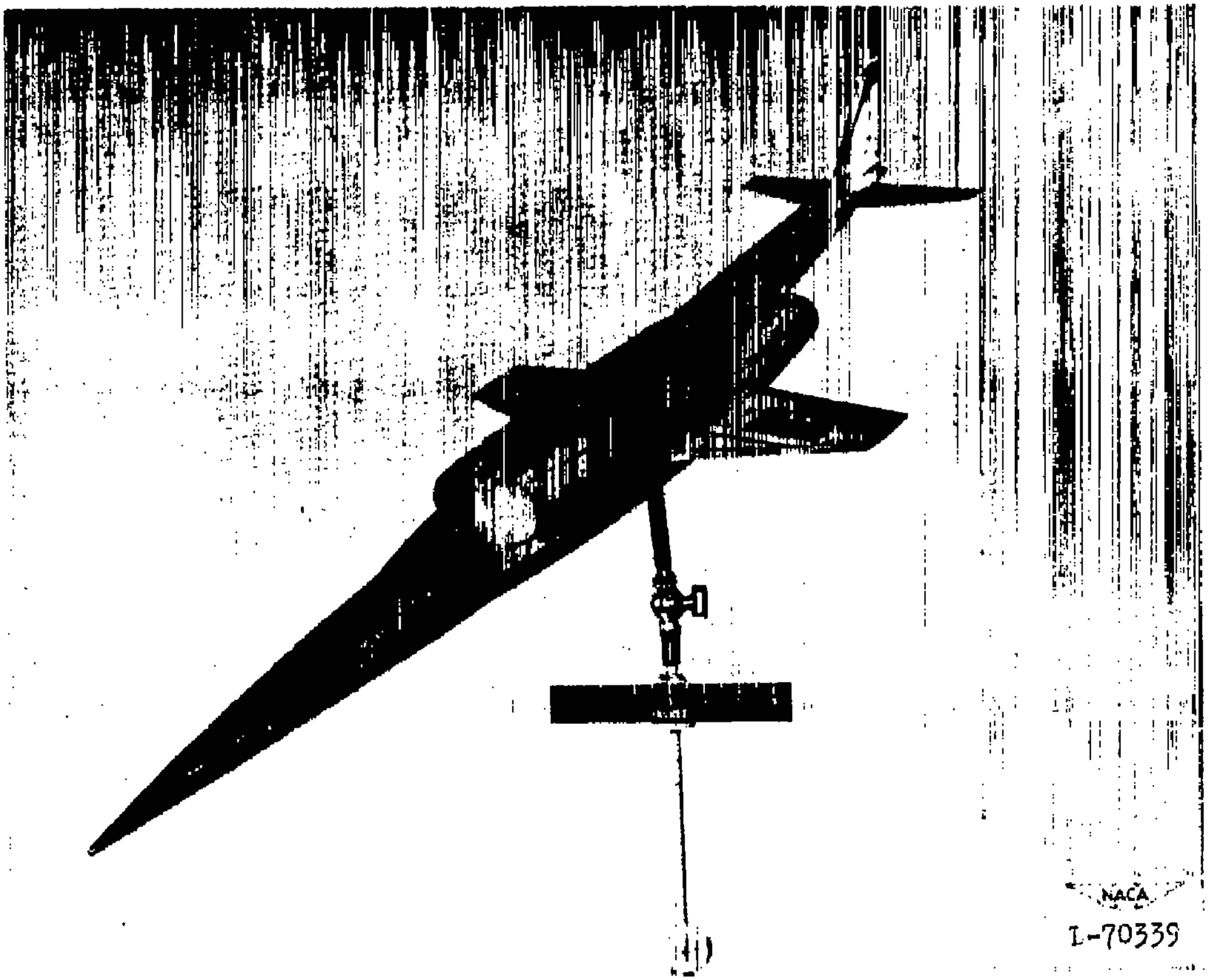

Figure 2.- Photograph of model with normal nose installed.

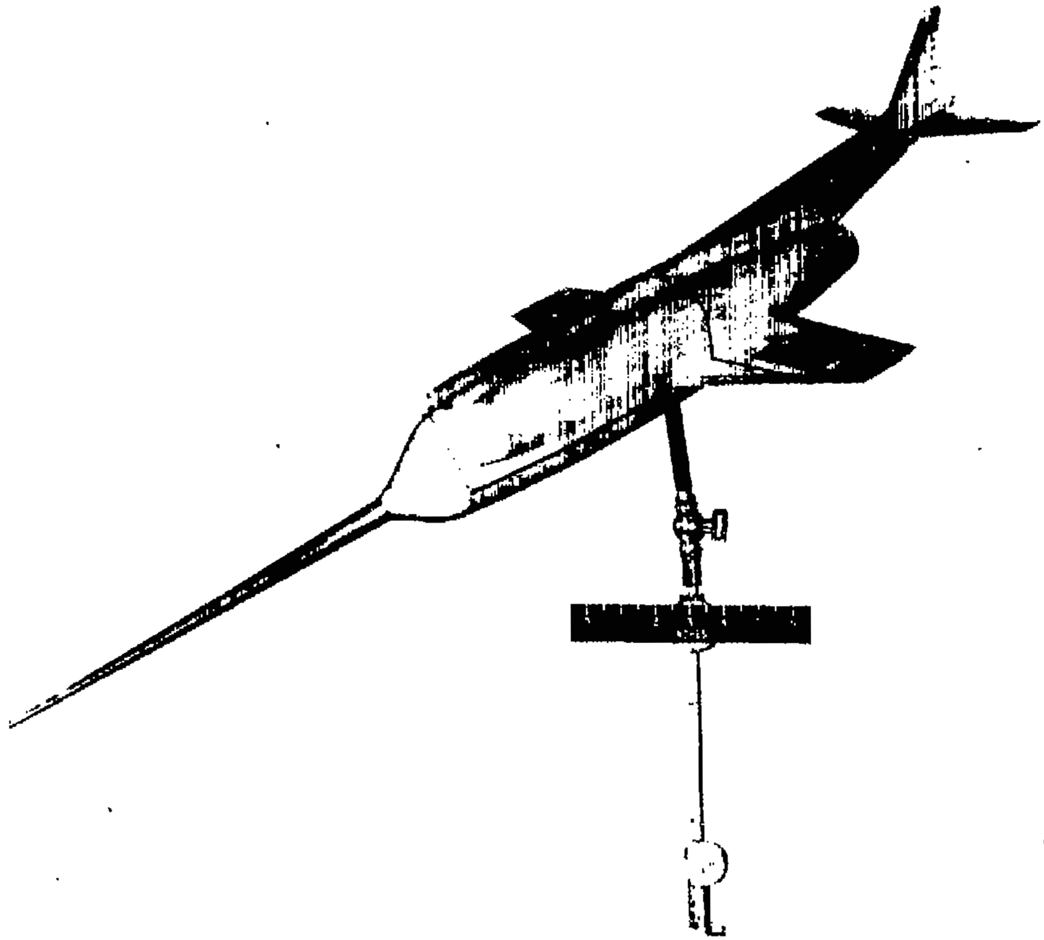

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Figure 3.- Photograph of modified model - sting nose installed.

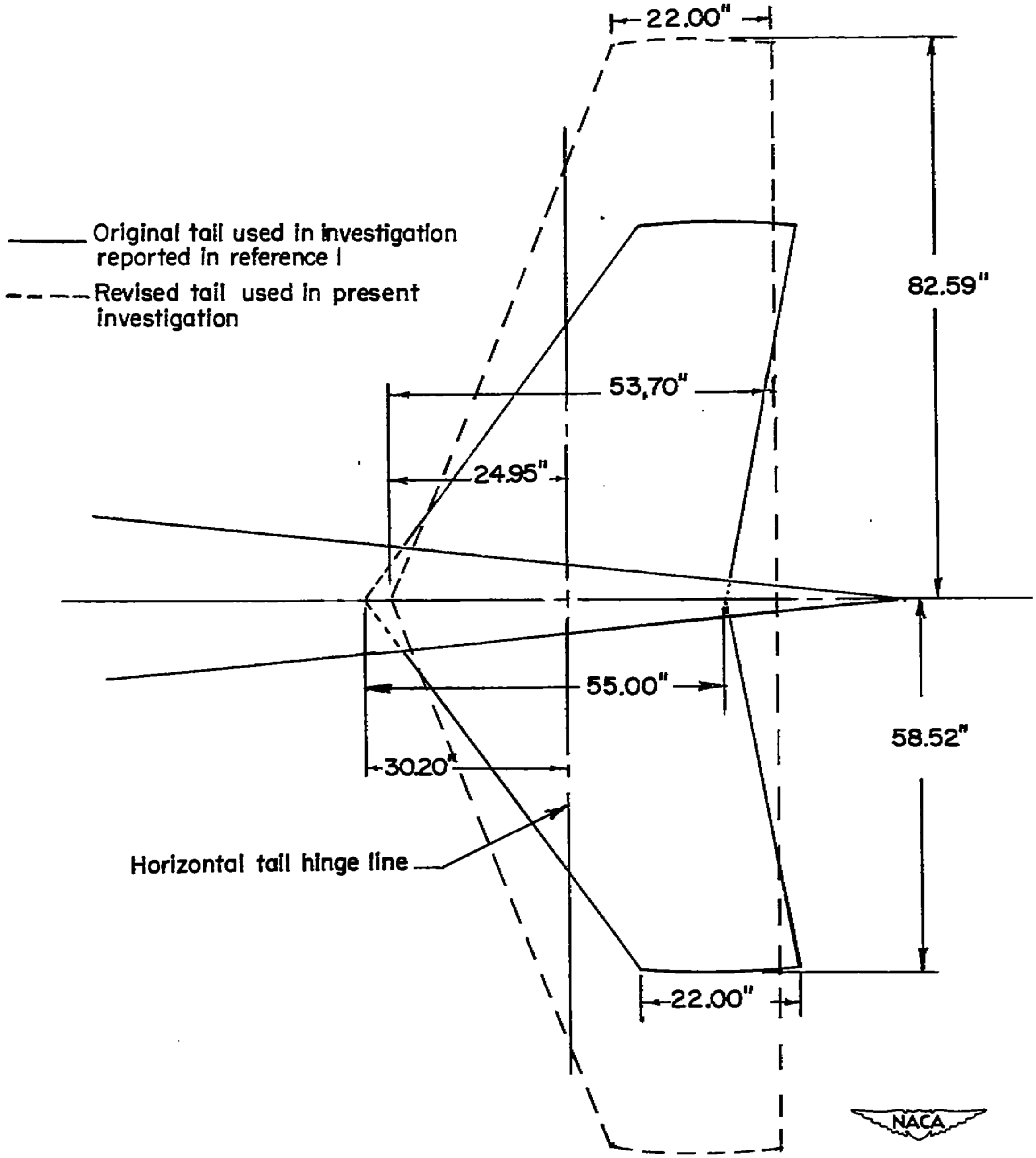

Figure 4.- Comparison of small horizontal tail used in the investigation of reference 1 and the horizontal tail used for the present dynamic tests. Dimensions are full scale.

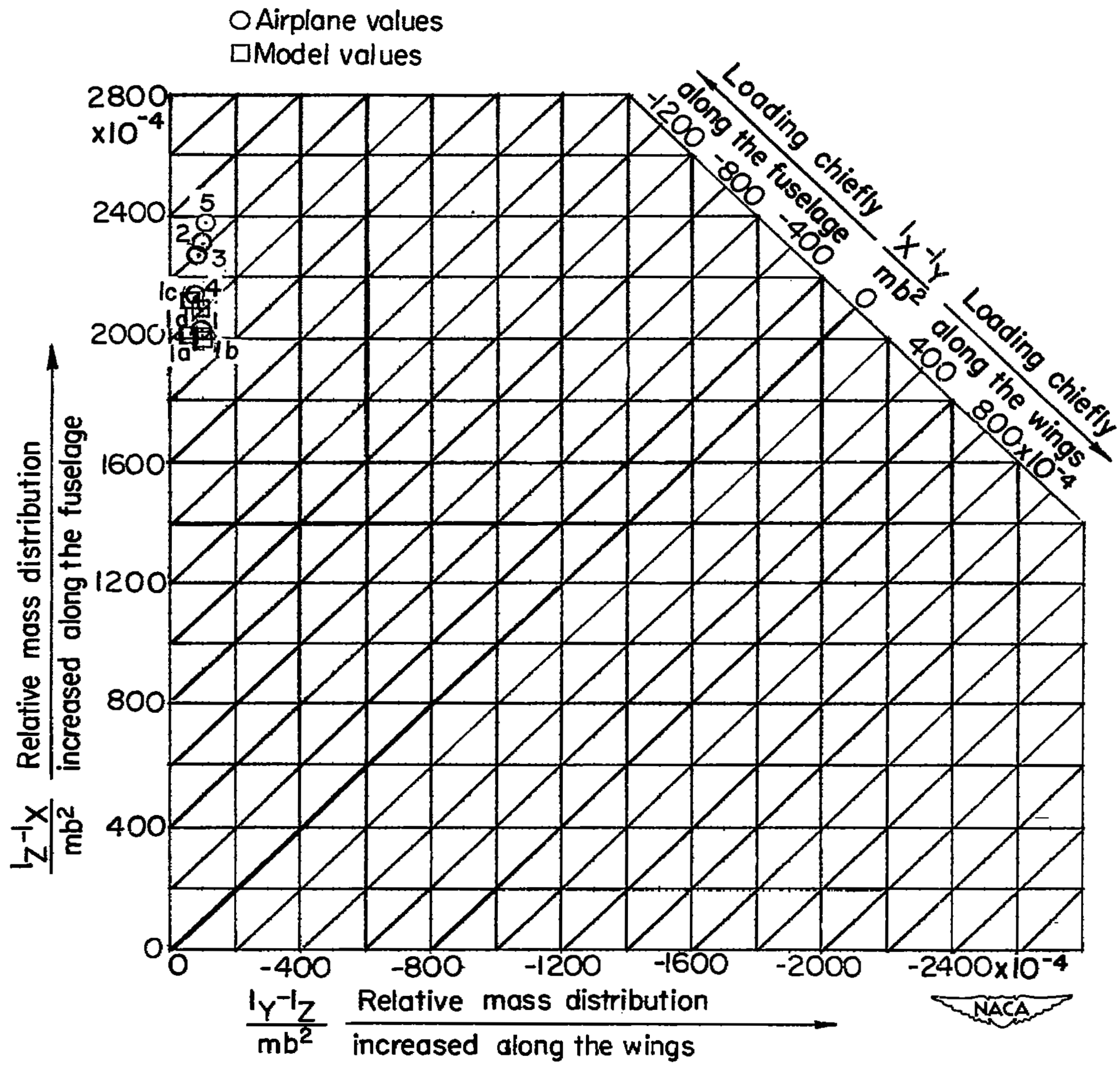

Figure 5.- Mass parameter plot for the various airplane loading conditions and for the conditions tested on the model as tabulated in table II.

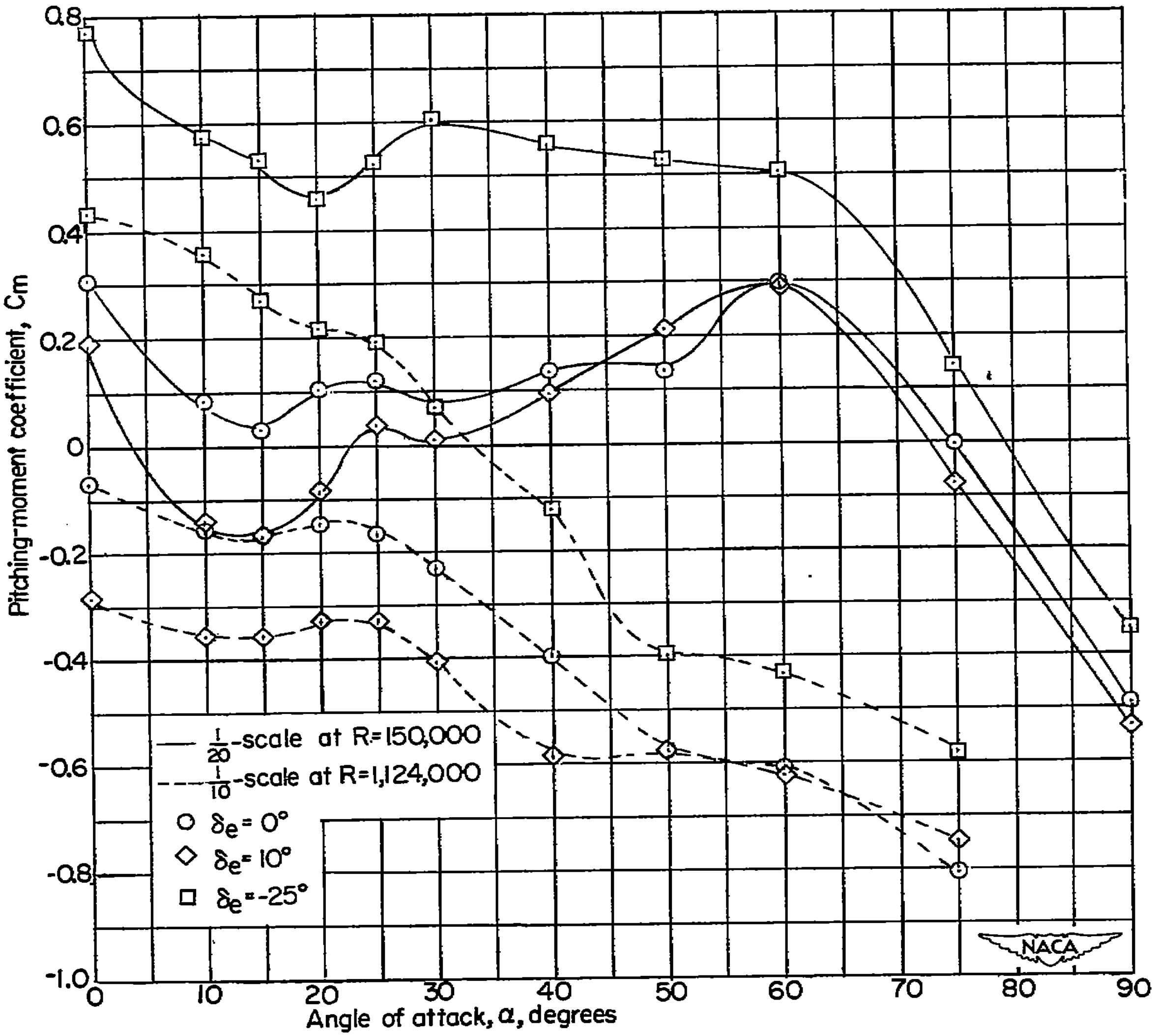

Figure 6.- Comparison of the pitching-moment characteristics of the the unmodified $\frac{1}{20}$ - scale model used in the current investigation and the larger scale model reported in reference 1. $\psi = 0^{\circ}$. (Small horizontal tail on both models.)

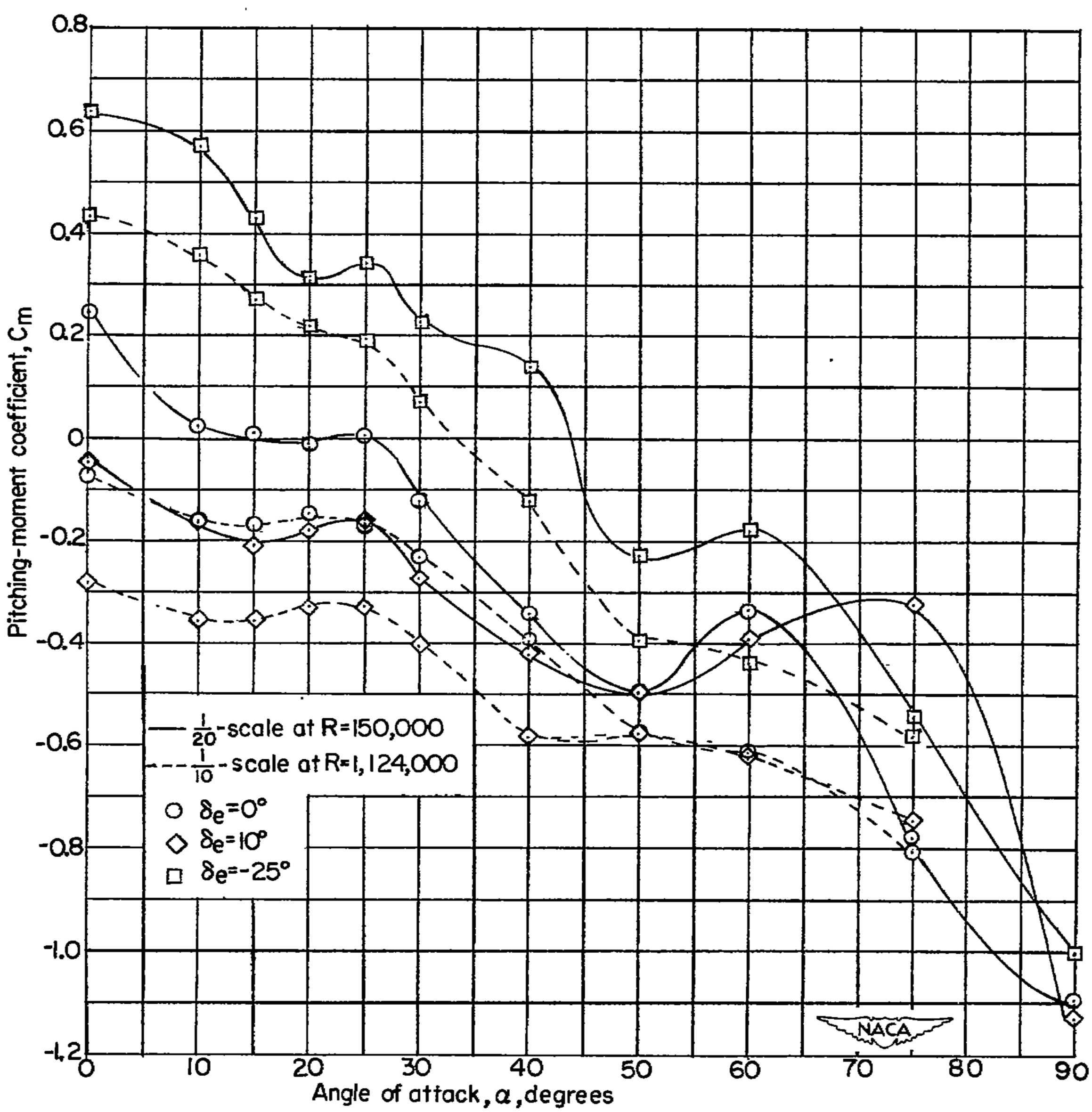

Figure 7.- Comparison of the pitching-moment characteristics of the modified $\frac{1}{20}$-scale model (sting nose installed) used in the current investigation and the larger scale model reported in reference 1. $\psi = 0^{\circ}$. (Small horizontal tail on both models.)

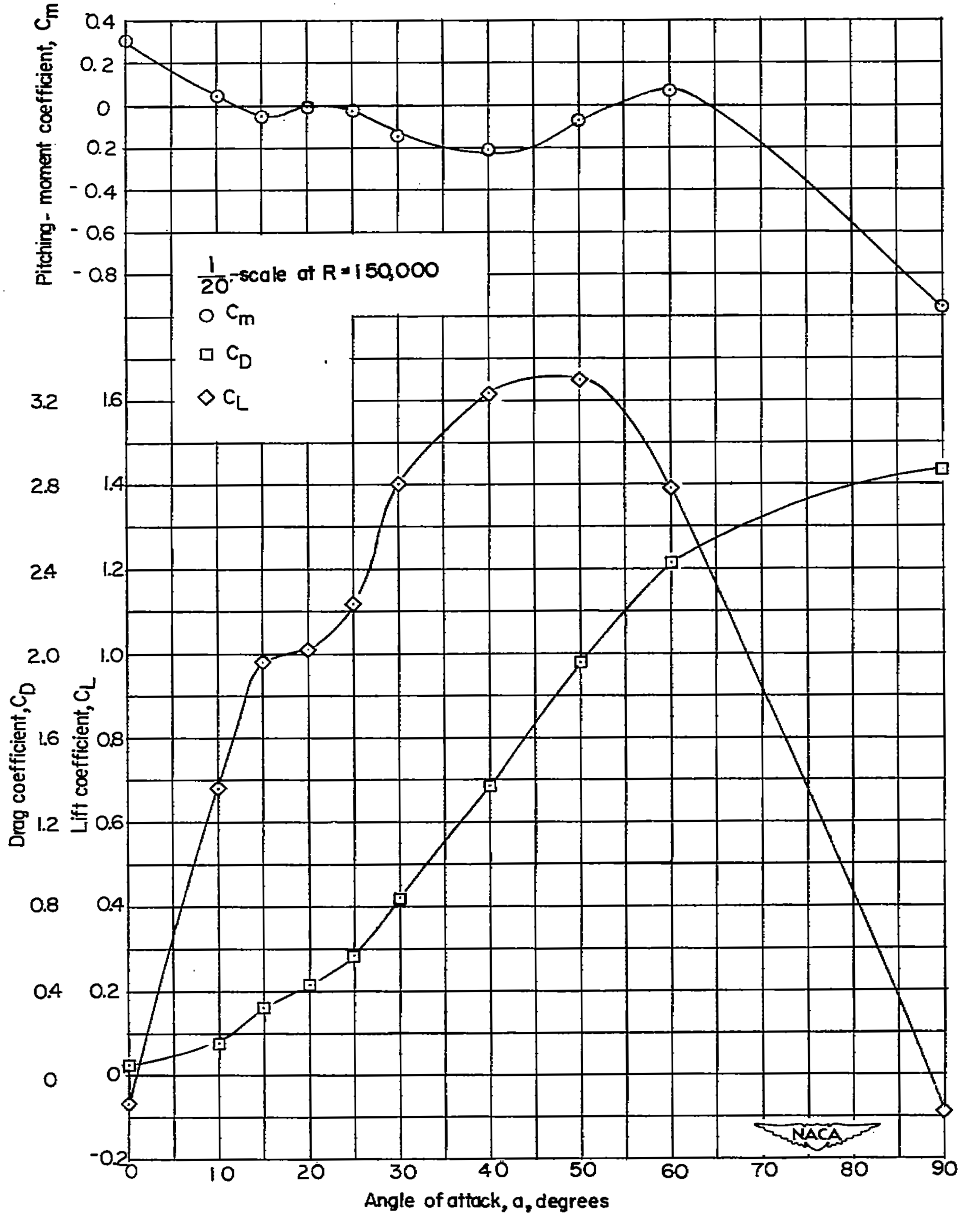

Figure 8.- Aerodynamic characteristics of the unmodified $\frac{1}{20}$ - scale model with large horizontal tail installed. $\psi = 0^{\circ}$. $\delta_e = 0^{\circ}$.